SAND2007-3386C

Fracture Behavior of Polyurethane Foams

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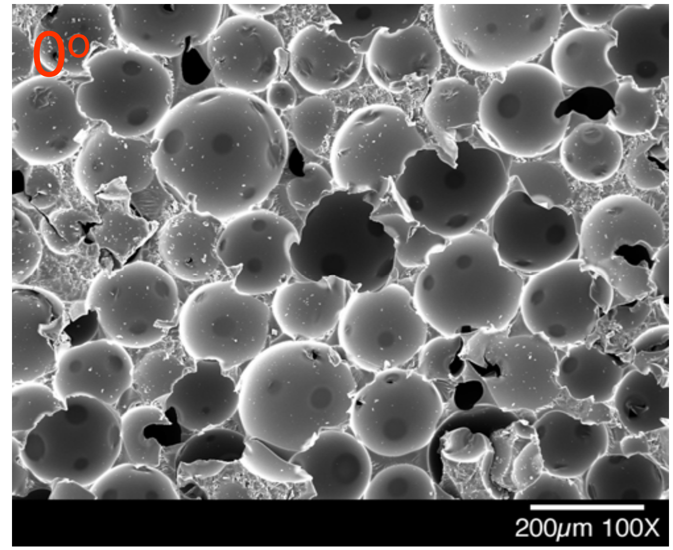
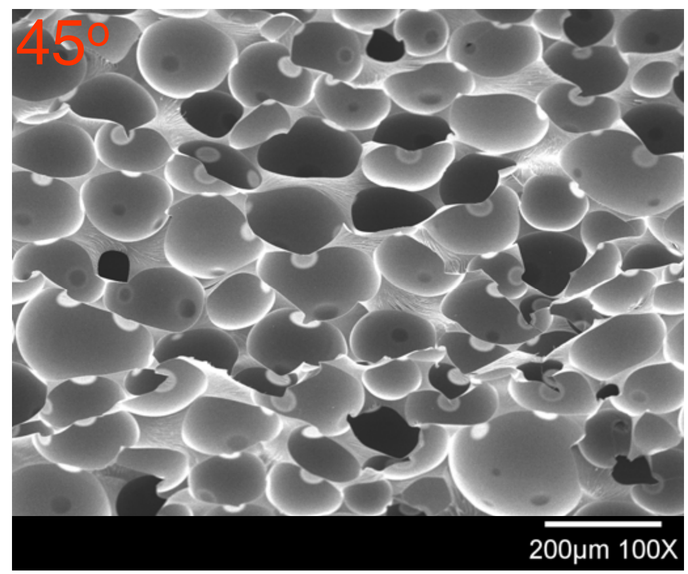
Investigated Material

- Closed cell polyurethane foam
- Nominal density of 20 pcf
- 8” diameter billet

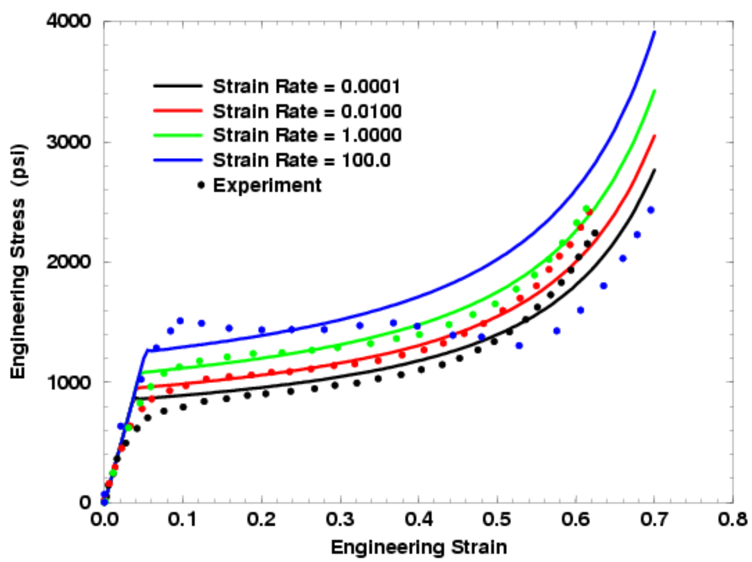
Billet of PMDI 20



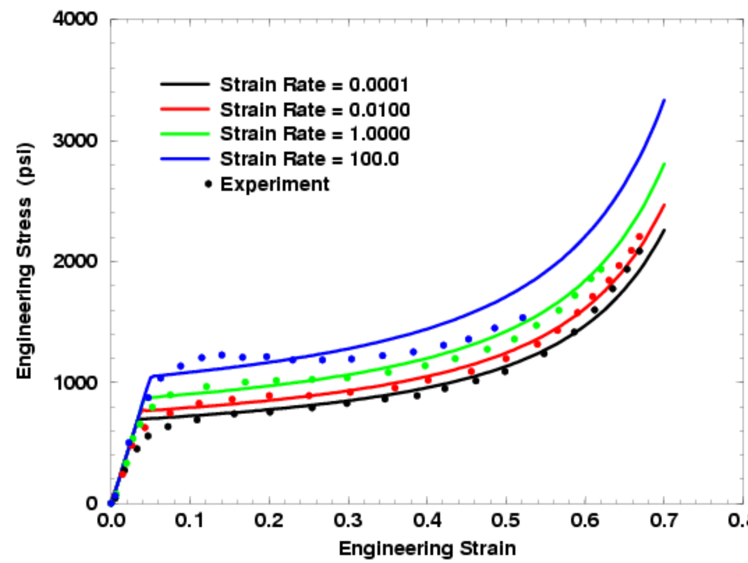


Background

- Characterization experiments of polyurethane (PU) foam materials at a wide range of strain rate and temperature were conducted to study
  - Effects of strain rate
  - Effects of temperature
- Viscoplastic Foam Model (VFM) based on the characterization tests were developed to predict the effects of temperature and strain rate



(a) 70°F



(b) 165°F

Simulation of characterization experiments using VFM

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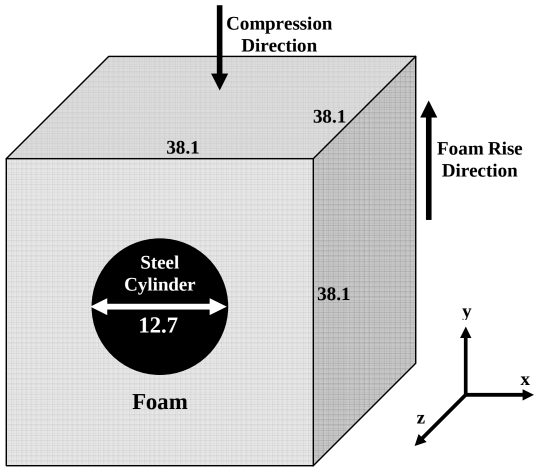
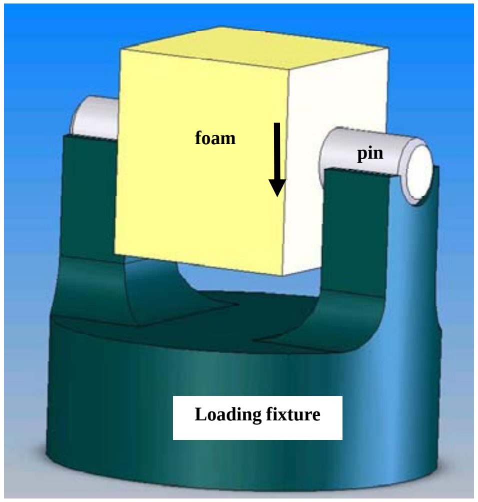
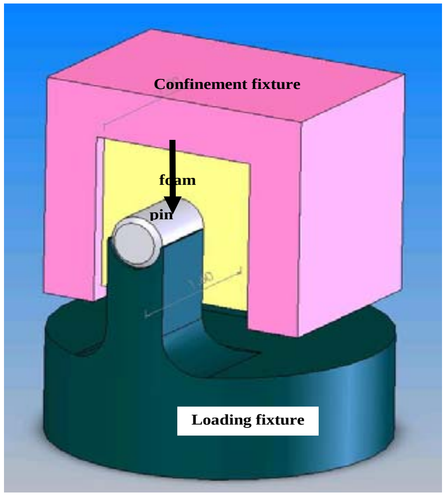
Model Validation Experiments



(I)



(II)



(III)

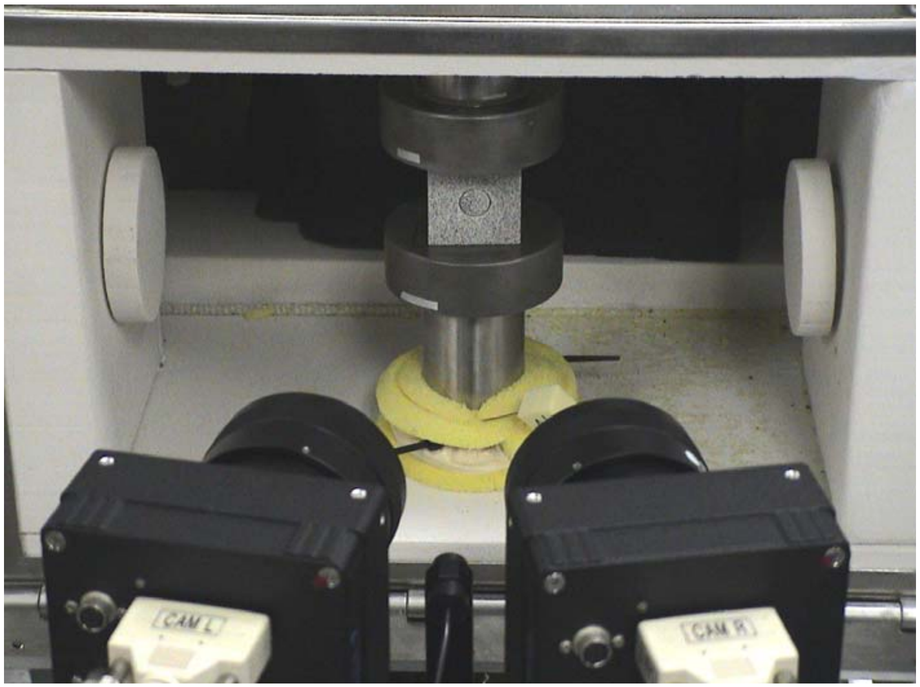
Three loading cases of foam with a steel pin inclusion are considered:

(1) Loading from top and bottom surfaces, representing the crush of a foam package;

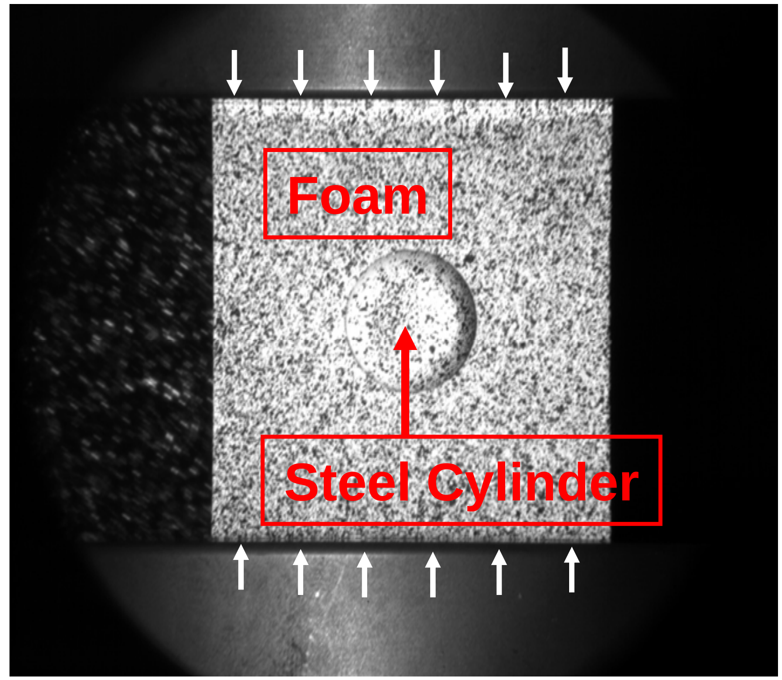
(2) Loading from top surface and pin, representing the drop of a foam package; and

(3) Same as (2), but the foam is confined to study the effects of confinement

Model Validation: Crush of Foam Package

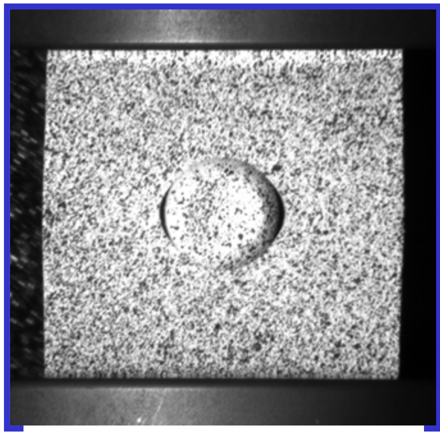


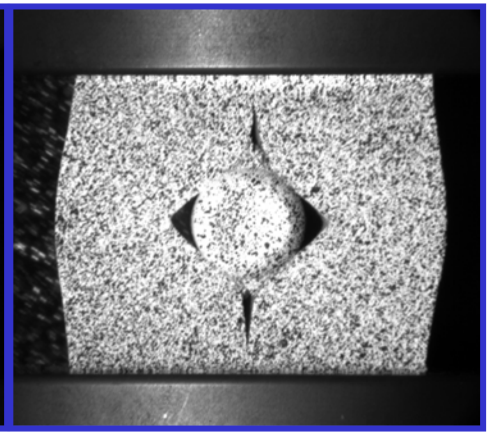
MTS 858 Mini Bionix with 3D-DIC System

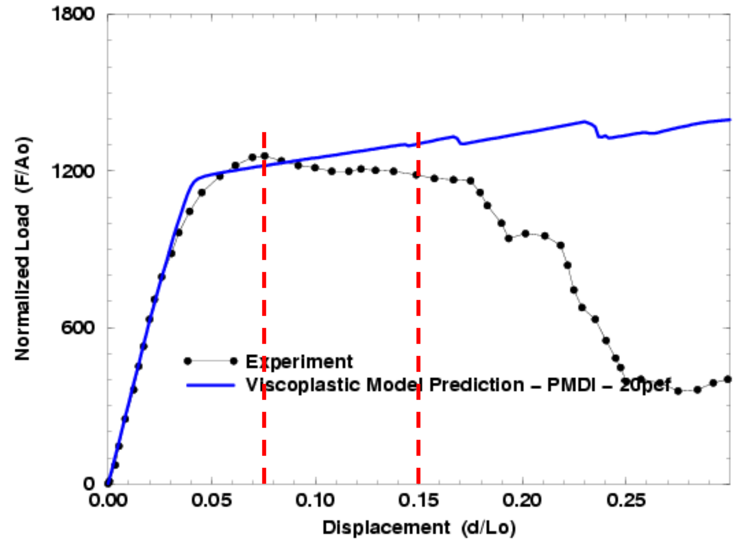


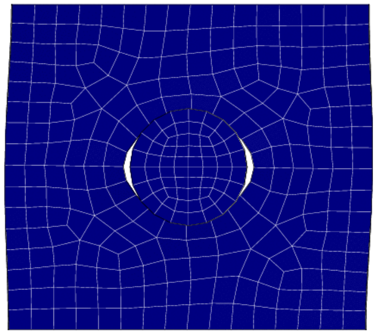
Experiment represents foam package crush

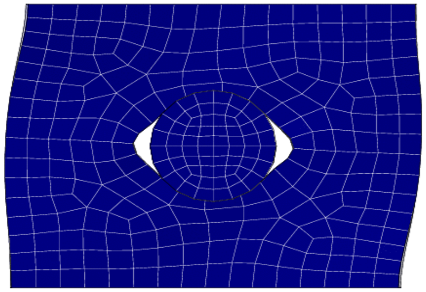
Simulation of Model Validation Test





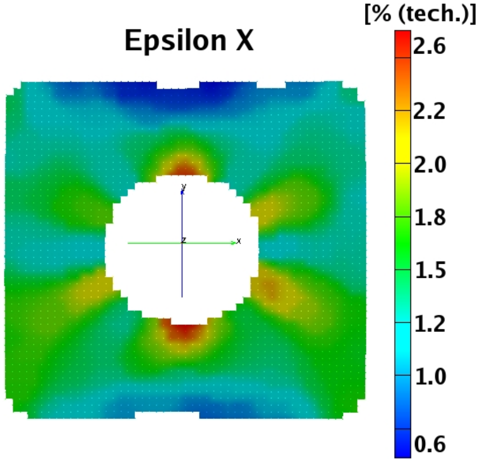






7.5% compression
Peak load

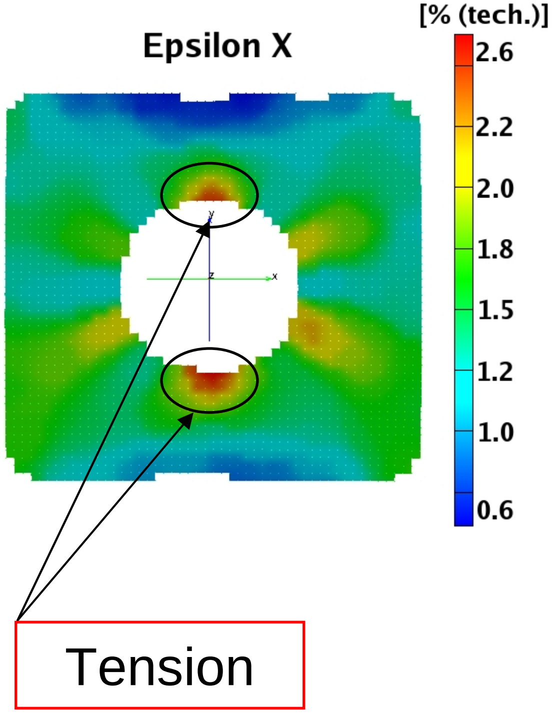
15% compression

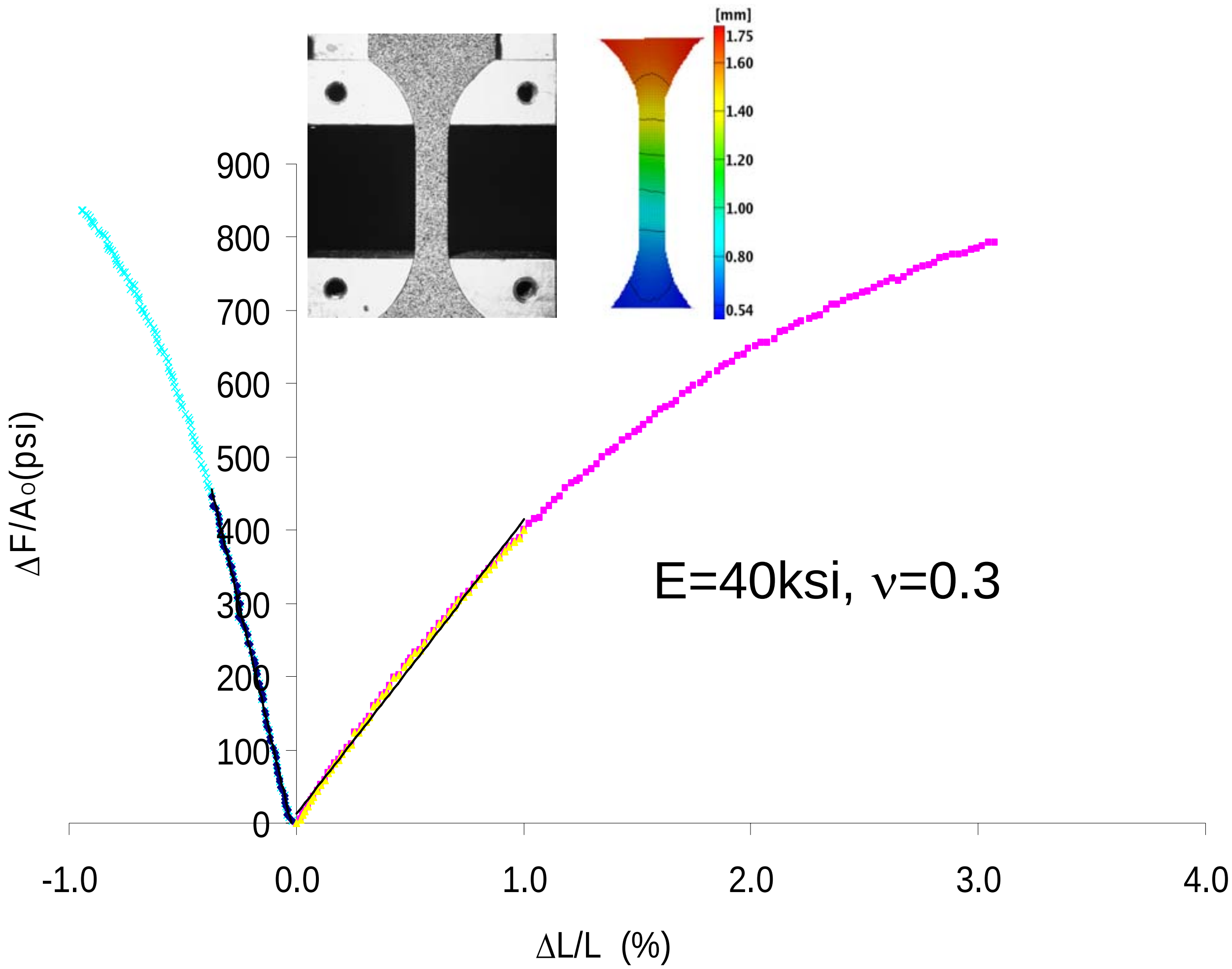


Failure criteria needs to be included in the viscoplastic foam model (VFM)

Tensile behavior of PMDI 20

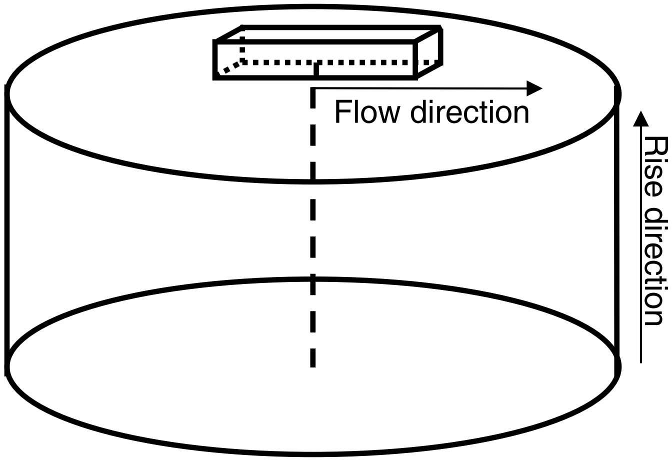
- Rigid Foam

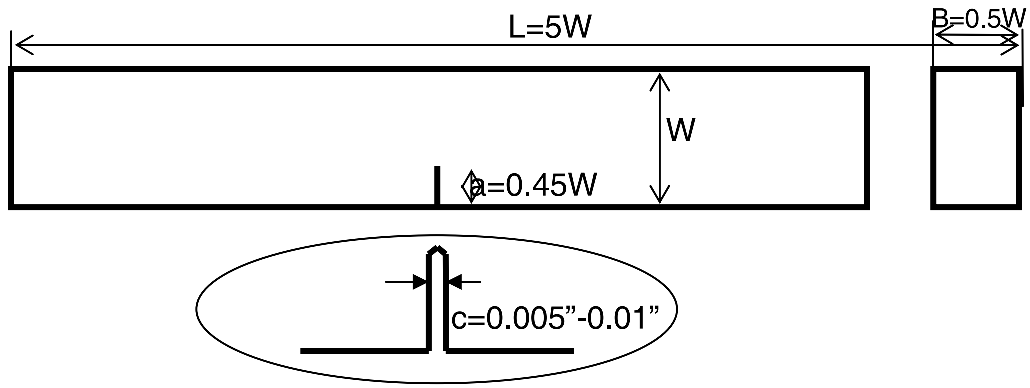




Typical Tensile Stress~strain curve for PMDI 20 at room temperature, rise direction

Foam Fracture Tests



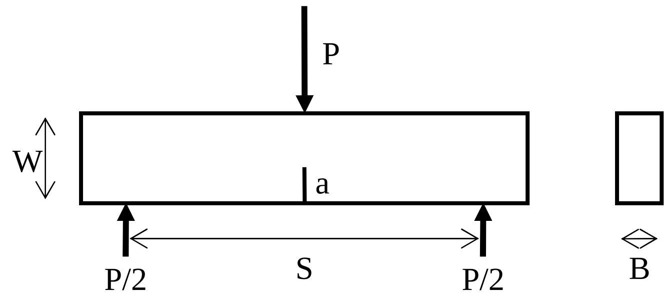


The crack is parallel to the foam rise direction

Matrix of different tests and specimens:

	A	B	C	D
W (in)	0.5	1	1	1
B (in)	0.25	0.5	0.5	0.5
L (in)	2.5	5	5	5
A (in)	0.225	0.45	0.45	0.45
Test	SENB	SENB	SENB	SENT

Fracture Toughness K_{Qc}

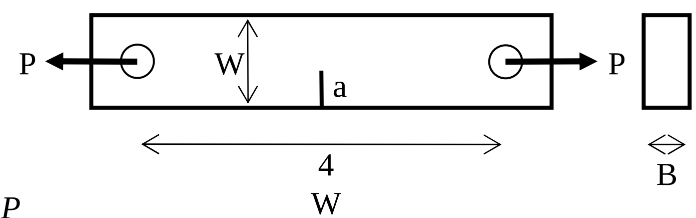


$$\sigma = \frac{6M}{BW^2} = \frac{3}{2}\frac{PS}{BW^2} \quad \left(M = \frac{PS}{4}\right)$$

$$K_I = \sigma\sqrt{\pi a}\,F(a/W)$$

For $S/W = 4$:

$$F(a/W) = 1.090 - 1.735(a/W) + 8.20(a/W)^2 - 14.18(a/W)^3 + 14.57(a/W)^4$$

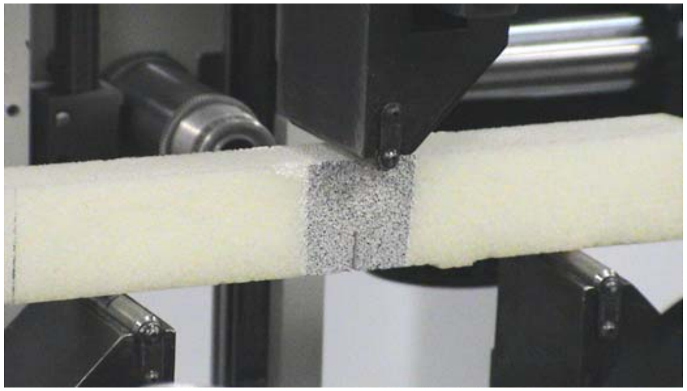


$$\sigma = \frac{P}{BW}$$

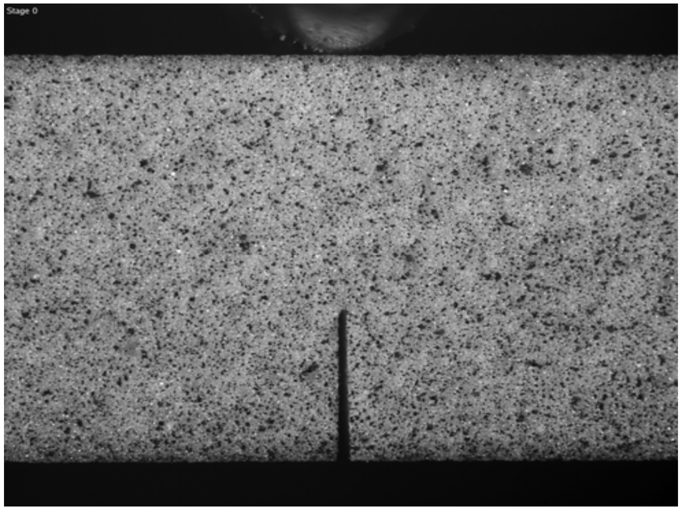
$$K_I = \sigma\sqrt{\pi a}\,F(a/W)$$

$$F(a/W) = 1.12 - 0.231(a/W) + 10.55(a/W)^2 - 21.72(a/W)^3 + 30.39(a/W)^4$$

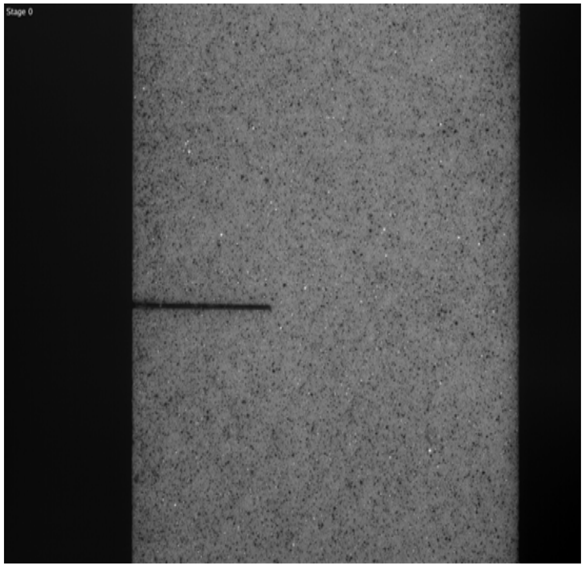
Foam Fracture Tests



Single Edge Notch Bending (SENB) setup

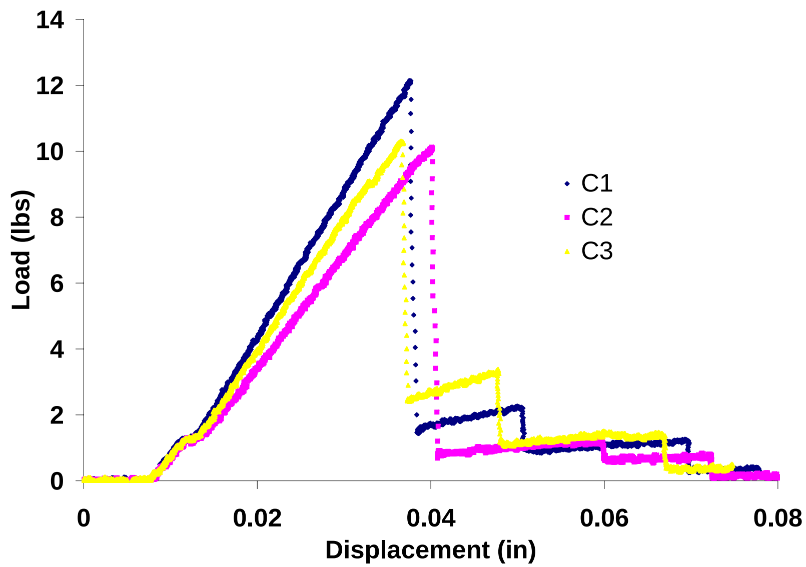


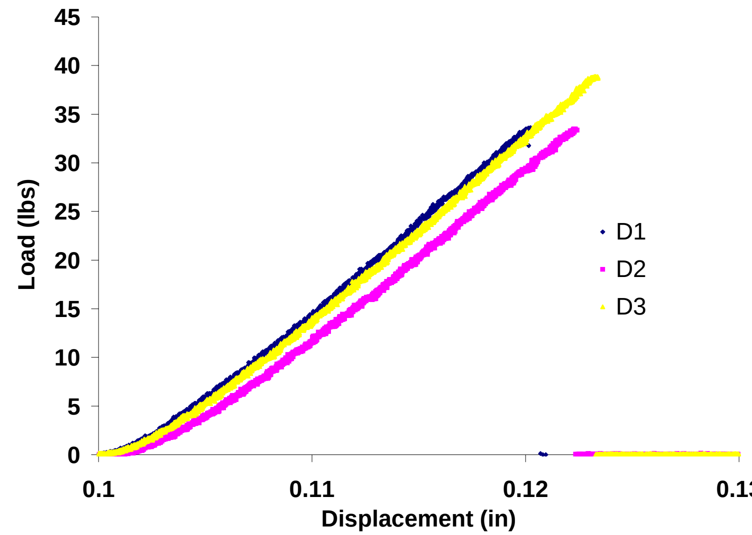
Single Edge Notch Tensile (SENT) setup

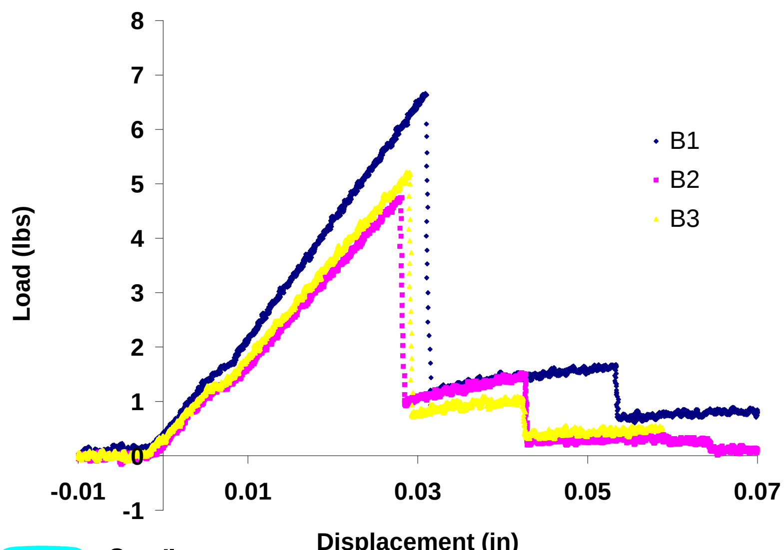


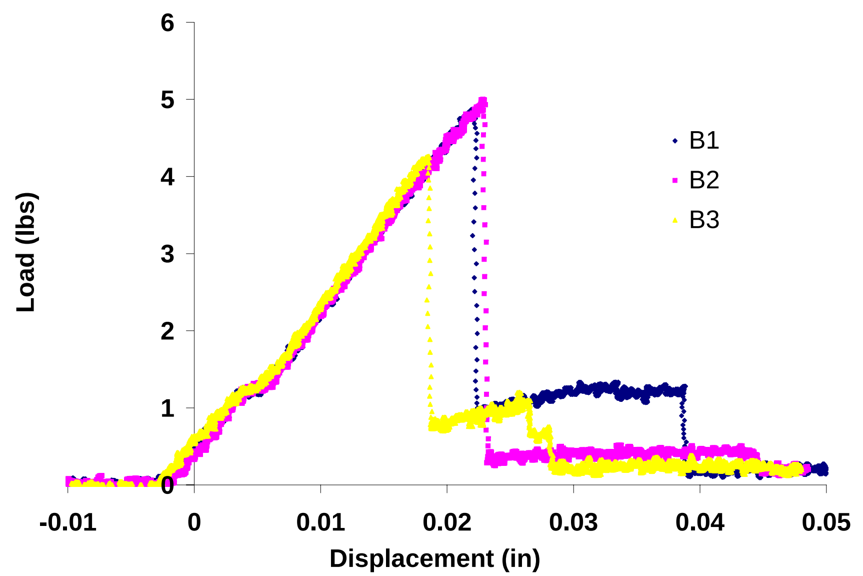
Area of Interest (AOI) for DIC

Load versus Displacement Curves









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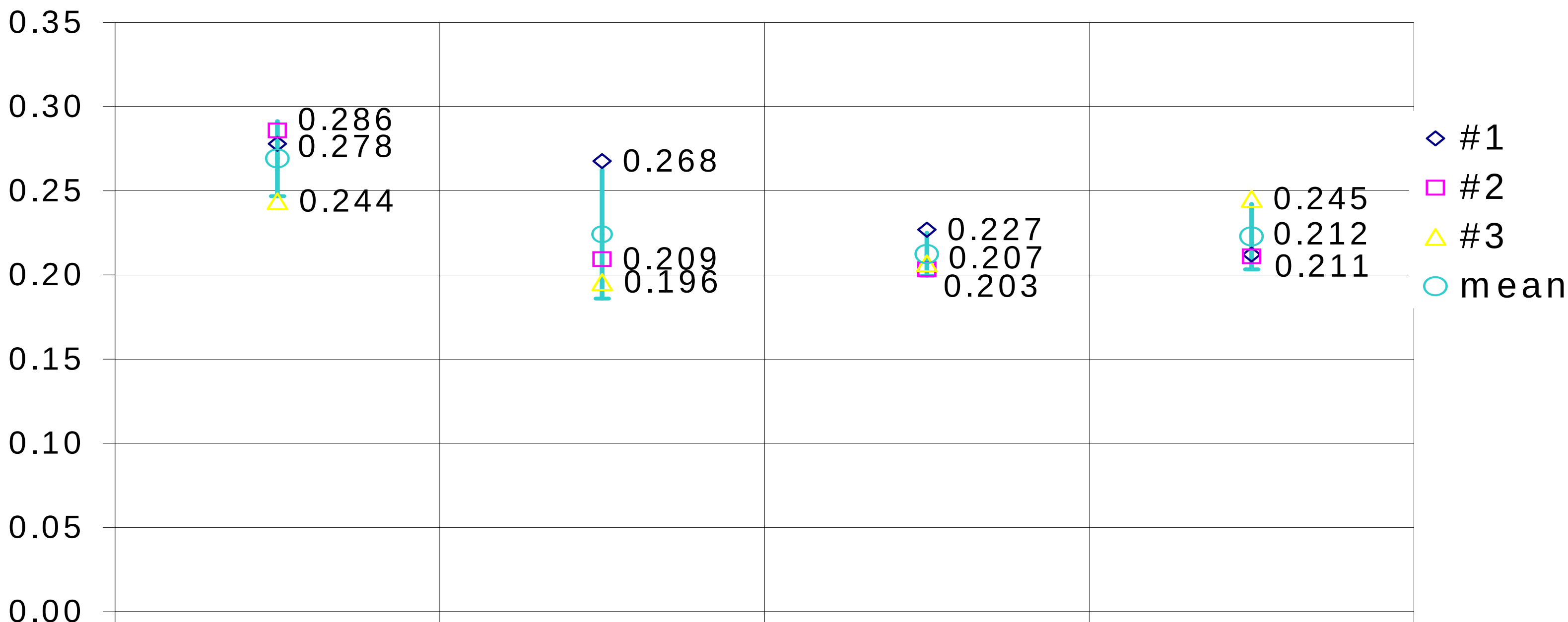
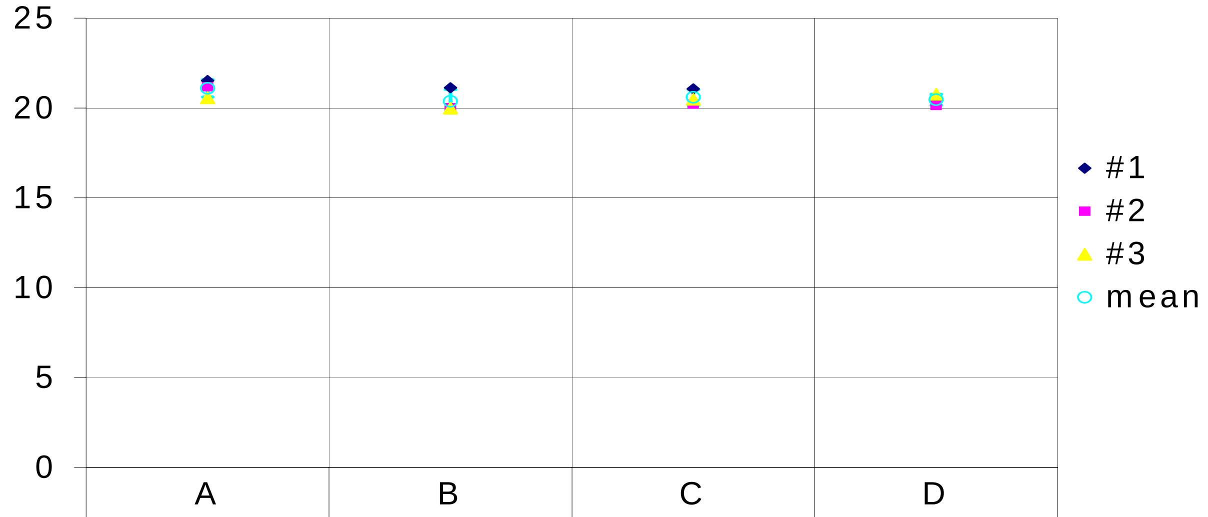
Fracture Toughness K_{Qc}



	A	B	C	D
#1	**0.278**	**0.268**	**0.227**	**0.212**
#2	**0.286**	**0.209**	**0.203**	**0.211**
#3	**0.244**	**0.196**	**0.207**	**0.245**
mean	**0.269**	**0.224**	**0.212**	**0.223**

Fracture Toughness Uncertainty

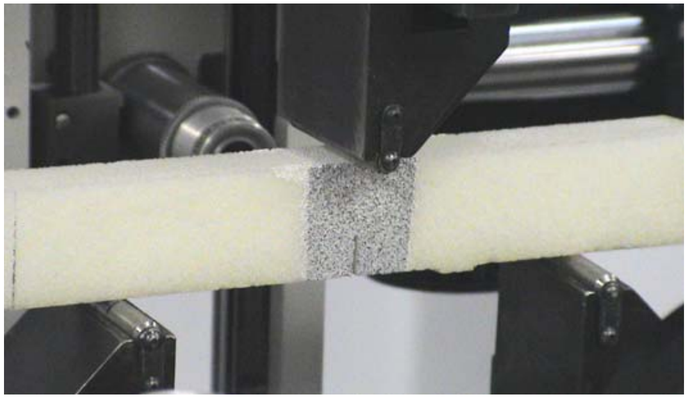
1. Density variation:



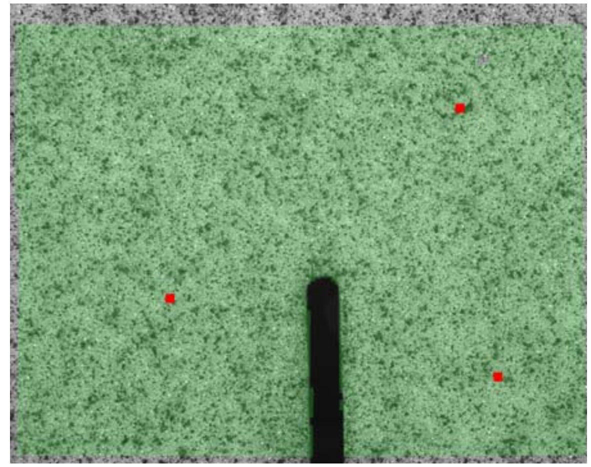
	A	B	C	D
#1	21.523	21.127	21.064	20.470
#2	21.181	20.008	20.214	20.135
#3	20.567	19.983	20.479	20.754
mean	21.091	20.372	20.586	20.453

2. Crack length uncertainty
3. Material inhomogeneity
4. Size effect

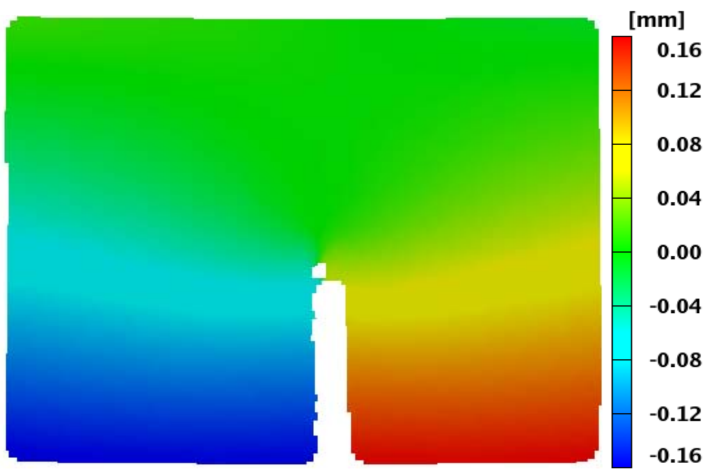
Full-field Deformation using DIC



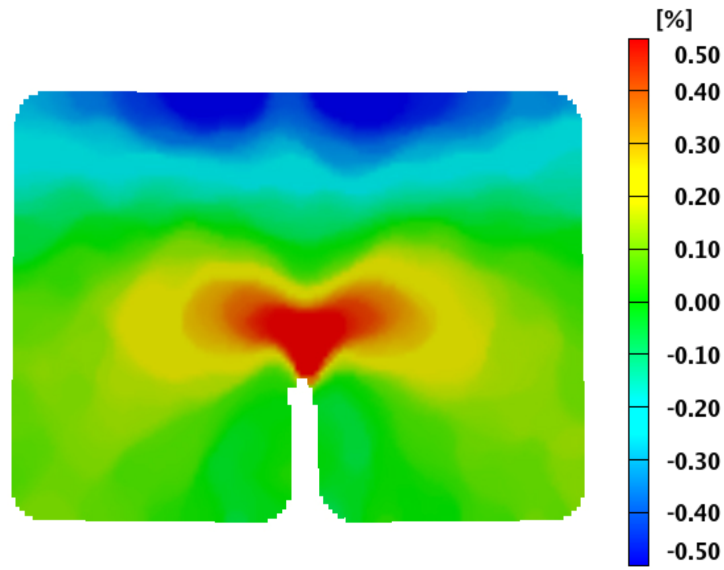
SENB setup



AOI for DIC



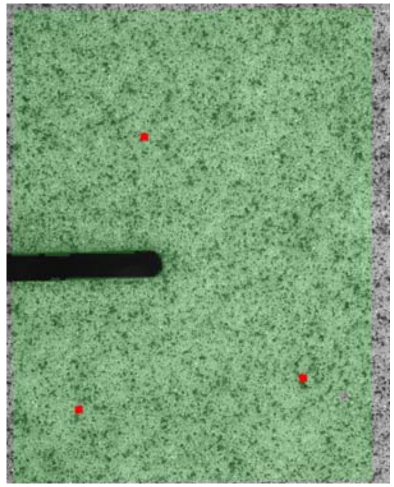
Displacement field U



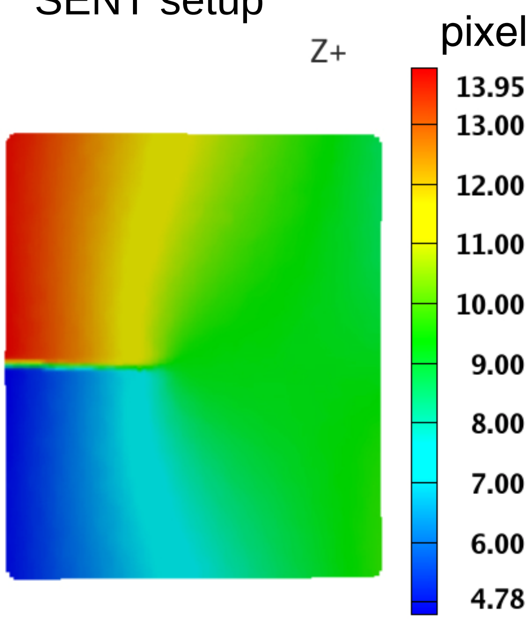
Strain field E_{xx}

Full-field Deformation using DIC

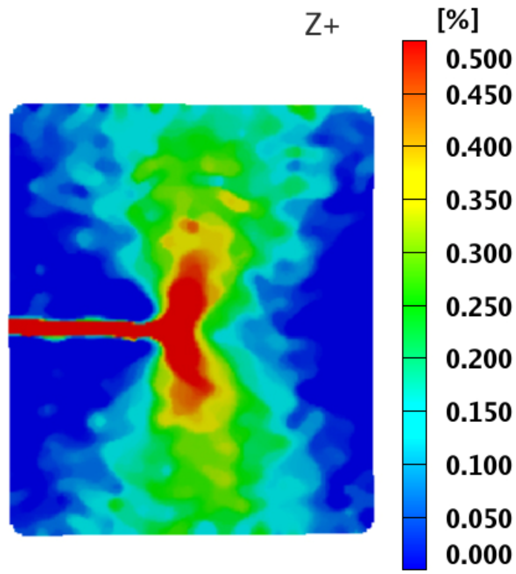
SENT setup



AOI for DIC



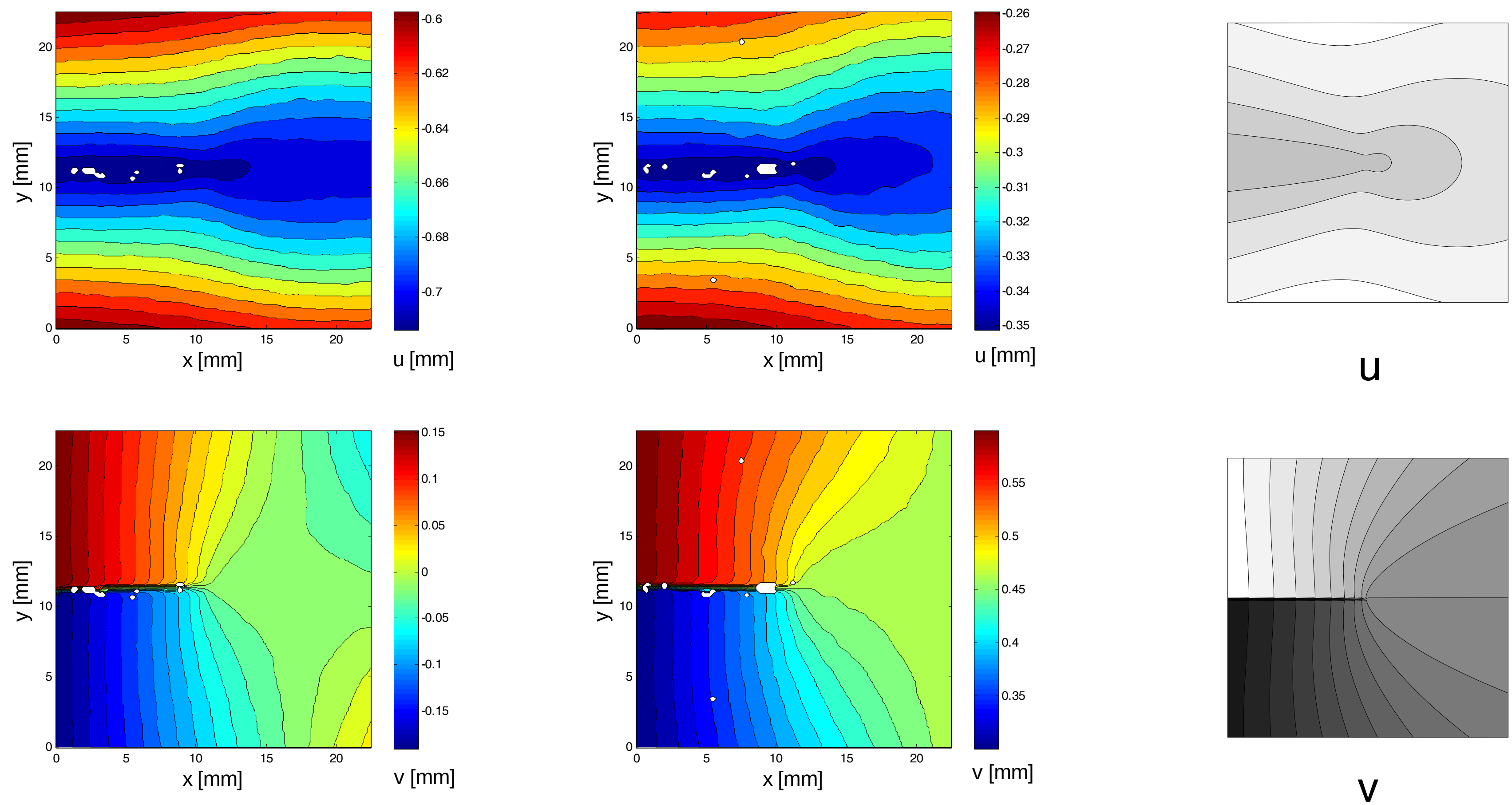
Displacement field V



Strain field E_{yy}

Crack-tip displacement field

SENB | SENT | Analytical K_I-field



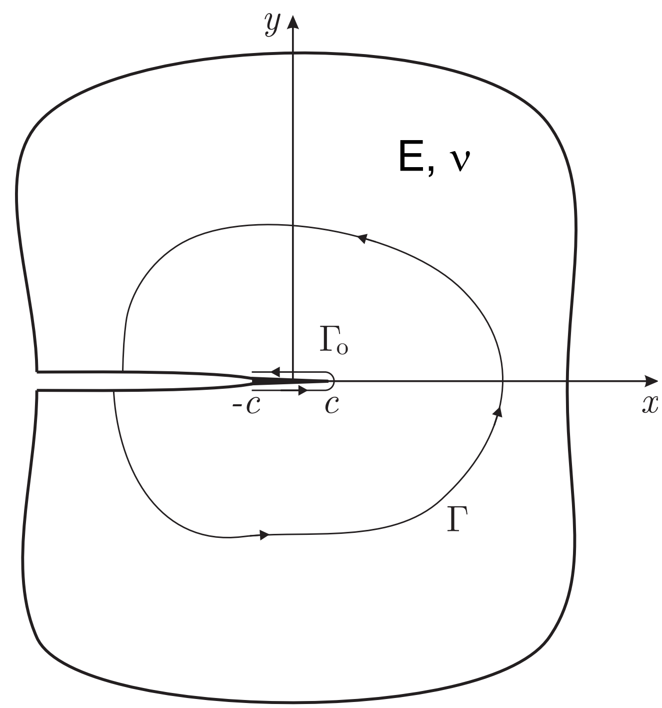
Path-independent integral

J contour integral

$$J = \int_{\Gamma} \left(\frac{1}{2} \sigma_{\alpha\beta} u_{\alpha,\beta} n_1 - \sigma_{\alpha\beta} u_{\beta,1} n_\alpha \right) ds$$

Energy release rate

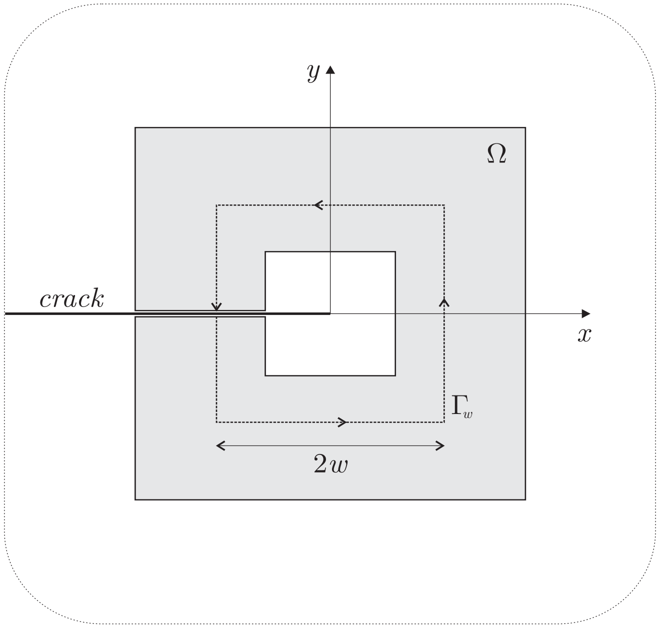
$$G = \frac{K_I^{\,2}}{E'}$$

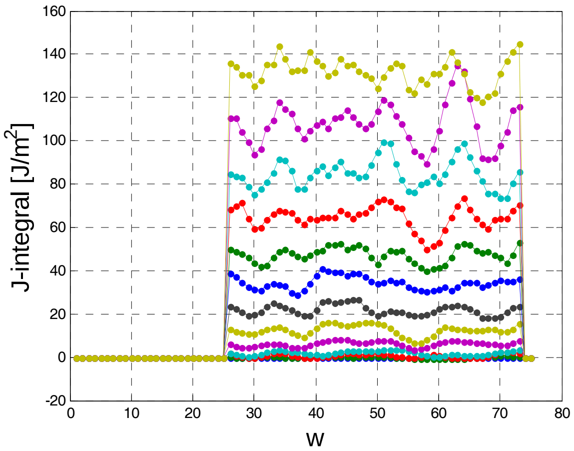


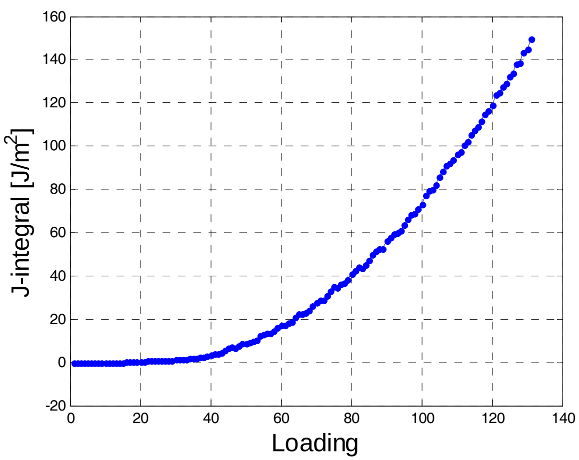
Elastic material under quasistatic condition (G=J)

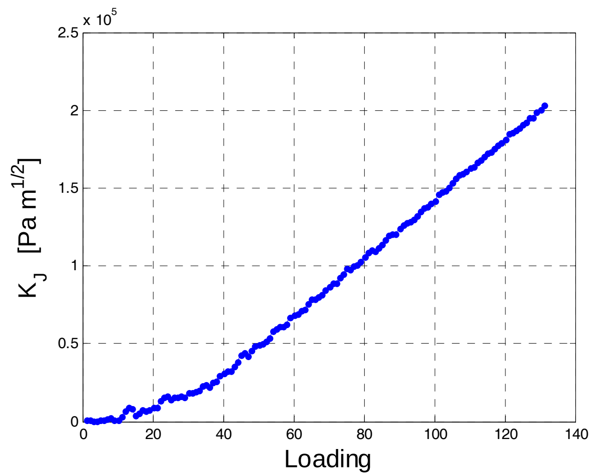
$$K_J = \sqrt{E'\,J}$$

Calculating J-integral

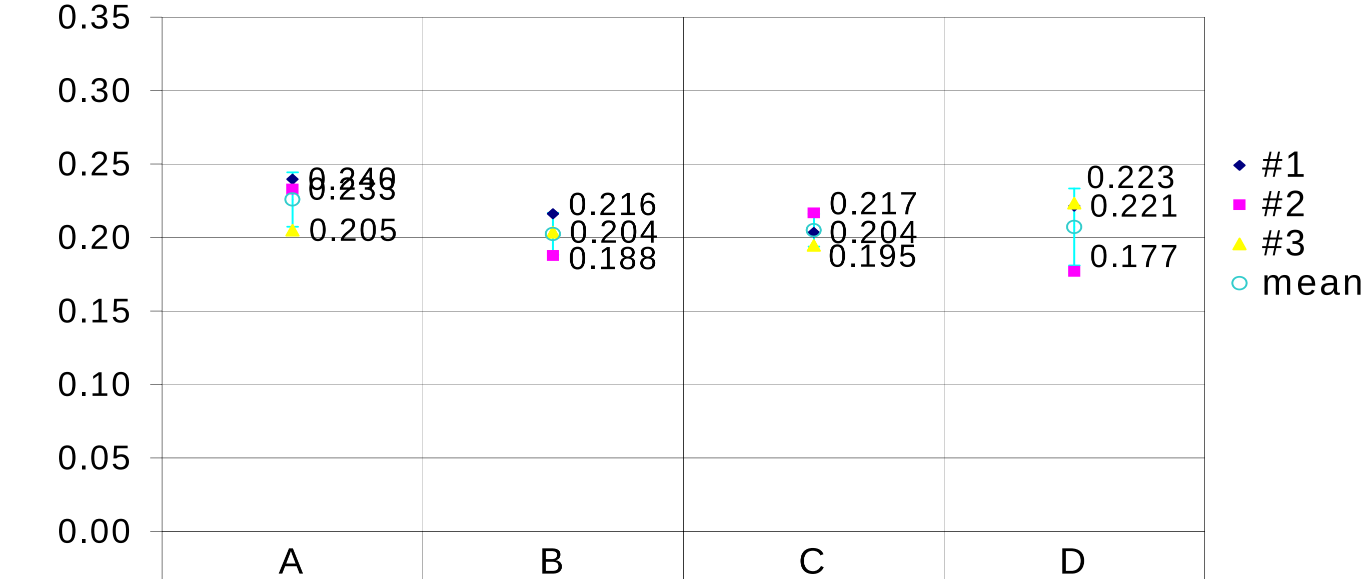








K_{Jc}



	A	B	C	D
#1	0.240	0.216	0.204	0.221
#2	0.233	0.188	0.217	0.177
#3	0.205	0.204	0.195	0.223
mean	0.226	0.202	0.205	0.207

Effects to $K_{Jc:}$ Young's modulus E, Displacement field

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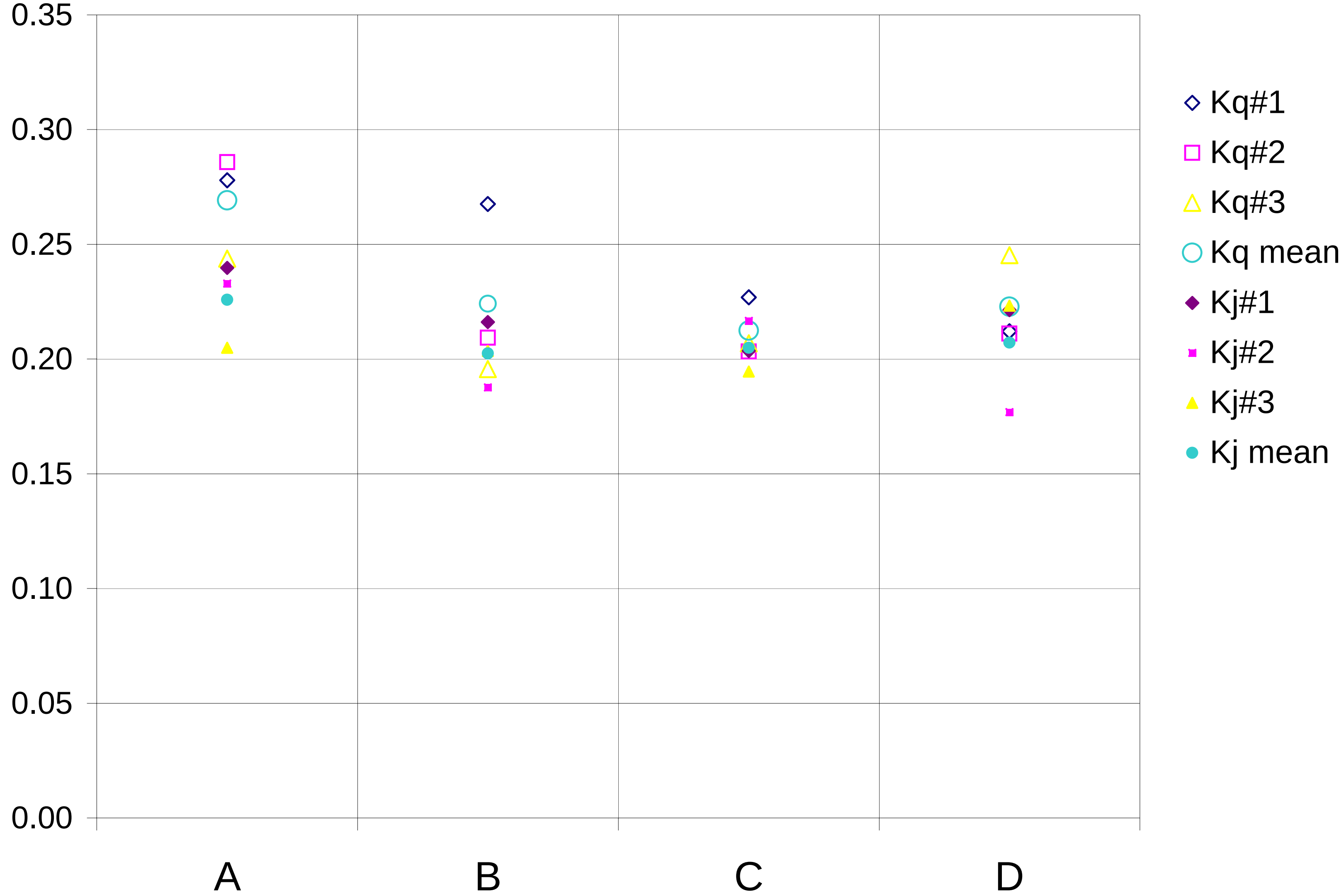
K_{Jc} and K_{Qc}



0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
A
B
C
D
Kq#1
Kq#2
Kq#3
Kq mean
Kj#1
Kj#2
Kj#3
Kj mean

Summary

- The fracture toughness of PMDI 20 was measured using both SENB and SENT under LEFM assumptions;
- DIC was applied to obtain the full-field displacement and strain around the crack tip;
- Path-independent J-integral was calculated from the DIC full field displacement;
- K_Q and K_{Jc} are overall matching well except for smaller size specimens, where K_J gives more accurate value.

Thank you!

Questions?